Milling

The Milling Operation

It is the operation in which metal is removed from work being fed against a rotating multipoint cutter. The cutter rotates at a high speed and because of the multiple cutting edges it removes metal at a very fast rate. That is why a milling machine finds application in production work.

Milling Machines

The first milling machine came into existence in about 1770 and it was of a French origin. The first successful plain milling machine was designed by Ell Whitney in the year 1818. After that the first universal milling machine was invented by R. Brown.

From that time till now a wide variety of milling machines of different capacities and designs has been developed. They are classified according to their designs to the following types:

1. **Column and knee type:**
   a. Plain horizontal milling machine.
   b. Universal milling machine.
   c. Vertical milling machine.
2. **Manufacturing or fixed bed type:**
   a. Simplex milling machine.
   b. Duplex milling machine.
   c. Triplex milling machine.
3. **Planer type**
4. **Special type:**
   a. Rotary table milling machine.
   b. Drum milling machine.
   c. Tracer controlled milling machine.

Column and knee type:

This is the most commonly used milling machine for general workshop activities. The table is mounted on the **knee casting** which in turn is mounted on the vertical slides of the main column. The knee is vertically adjustable on the column so that work of different heights can be accommodated on the table. The **column and knee type** is subdivided according to the various movements of its parts to the following types:

a. **Plain horizontal milling machine**

The plain milling machine of the horizontal type is shown in figure (1). Its table may be fed by hand or power against the rotating cutter. The last is being mounted on an arbor. The table can be fed in a longitudinal, cross or vertical directions. The feed is longitudinal when the table is moved at right angle to the spindle, it is cross when the table is moved parallel to the spindle and the feed is vertical when the table is adjusted in the vertical plane.

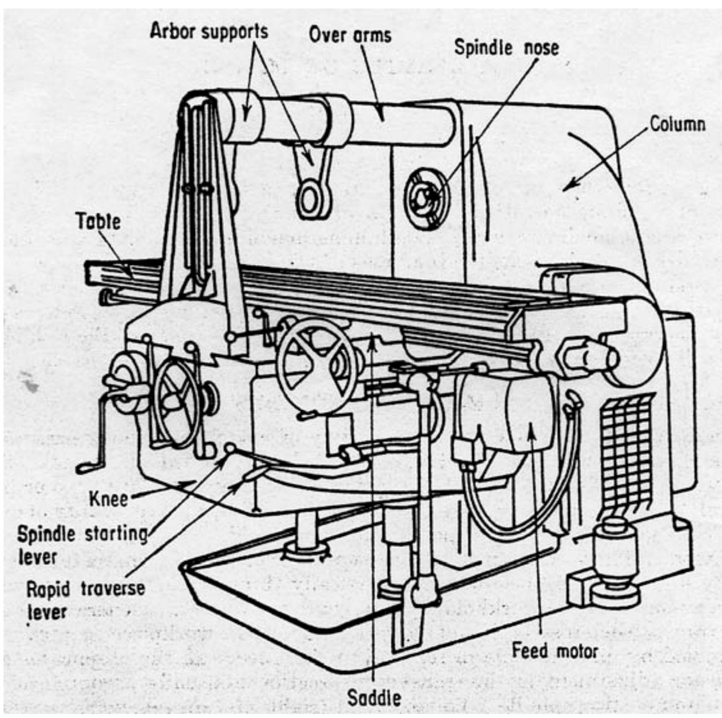


Fig. (1): Plain Horizontal knee type milling machine

b. **Universal milling machine:**

It is named so because it may be adapted to a very wide range of milling

operations. A universal milling machine can be distinguished from a plain milling machine in that the table in the universal milling machine is mounted on a circular swiveling base which has degree graduations. Thus the table can be swiveled to any angle up to ±45° around a vertical axis. This fourth movement of the table (in addition to the 3 existing ones in the plain milling machine) allows the table to be fed at an angle to the milling cutter and thus helical gears can be produced. There are a wide variety of special attachments (such as dividing head, vertical milling attachment, rotary attachment …etc.) increasing the capacity of the universal milling machine.

c. Vertical milling machine:

A vertical milling machine as shown in figure (2) can be distinguished from a horizontal one by the position of its spindle, which is vertical or perpendicular to the work table. The machine may be of plain or universal type. The spindle head which is clamped to the vertical column may be swiveled at an angle, permitting the milling cutter to work on angular surfaces. The machine is adopted for machining grooves, slots and flat surfaces. The end mills and face milling cutters are frequently used on this machine.

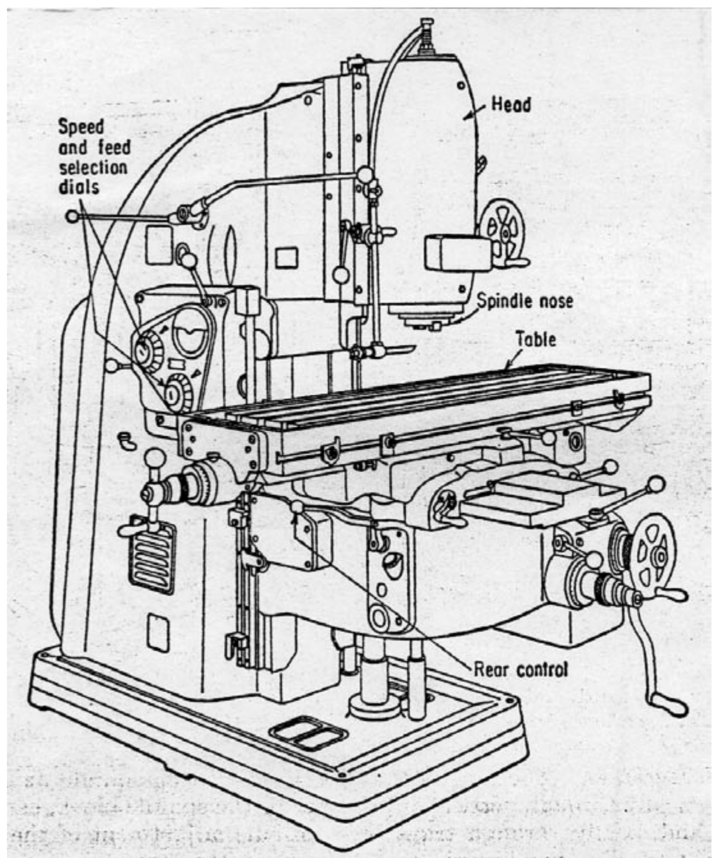


Fig. (2): Vertical knee type milling machine

Manufacturing or fixed bed type:

The fixed bed type milling machines are comparatively large, heavy, rigid and differ

radically from column and knee type milling machines by the construction of its table mounting. The table is mounted directly on the ways of fixed bed. Its movement is restricted to reciprocating at right angles to the spindle axis without any provision for cross or vertical adjustment. The name simplex, duplex and triplex indicates that the machine is equipped with, 1, 2 and 3 spindle heads respectively. The usual feature of these machines is the automatic cycle of operation for feeding the table that is repeated in a regular sequence. Figure (3) illustrates a bed type milling machine.

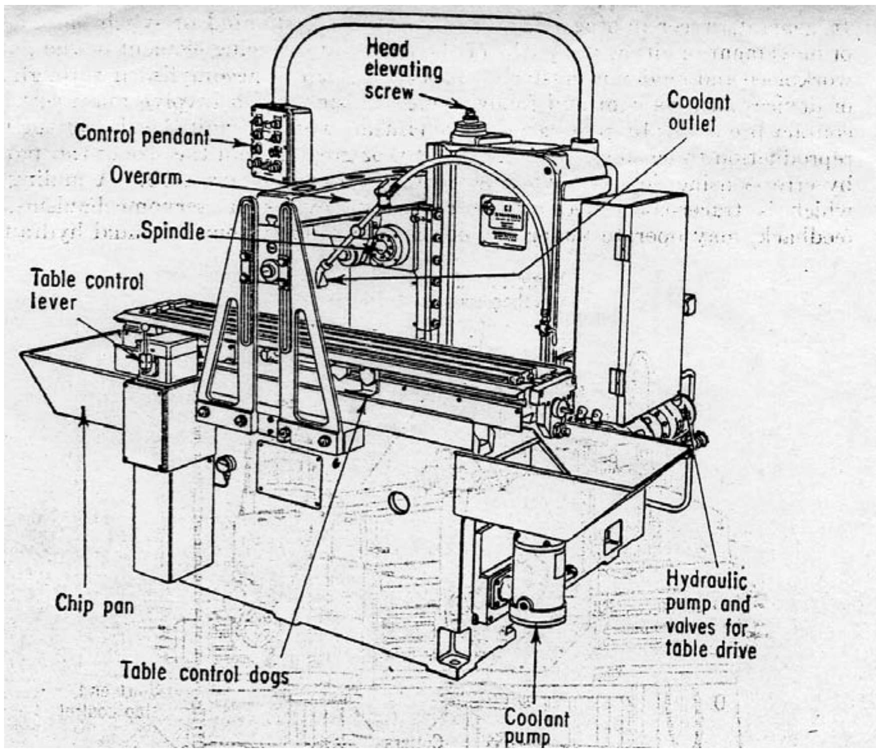


Fig. (3): Manufacturing or fixed-bed type milling machine

Planer type:

The plano-miller (figure 4) as it is called, is a massive machine built up for heavy duty work, having spindle heads adjustable in vertical and traverse directions. It resembles a planer and like a planing machine, it has a cross rail capable of being raised or lowered carrying the cutters, their heads, and the saddles. All supported by right uprights. Spindle heads can be mounted on the rail as well as on the uprights, which enable the different surfaces of the work being machined simultaneously and consequently increase productivity. The essential difference between a planer and a

plano-miller lies in the table movement and the type of cutters. In planer the table moves to give the cutting motion, but in a plano-miller it gives the feed motion.

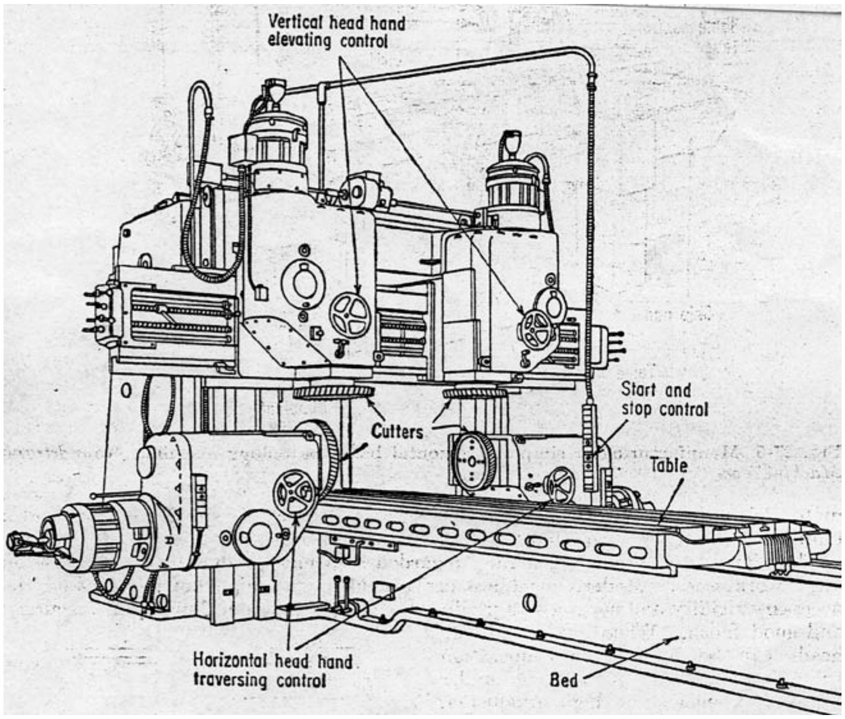


Fig. (4): Plano-miller

Special type:

The special type milling machines are distinguished with non-conventional designs suiting special purposes. They can have the following types:

a. **rotary table machine:**

   The construction of the machine is a modification to a vertical milling machine and is adapted for machining flat surfaces at a high production rate as shown in figure (5). The face milling cutters are mounted on two or more vertical spindles and a number of identical workplaces are clamped on the horizontal surface of a circular table, which rotates about a vertical axis. The cutters may be set at different heights relative to the work so that one of the cutters is roughing and the other finishing. A continuous loading and unloading of workpieces may be carried out by the operator while the milling is in progress.

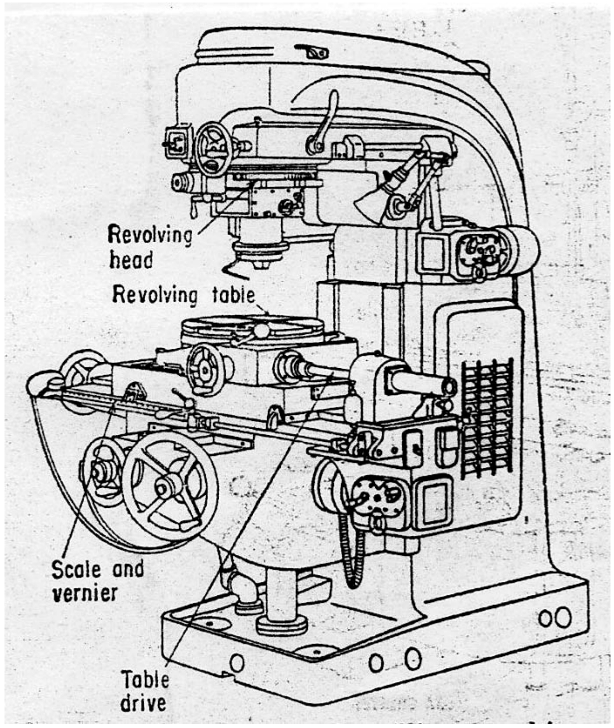


Fig. (5): Rotary-table milling machine

b. Drum milling machine

The drum milling machine is similar to a rotary table milling machine in that its work-supporting table, which is called a drum, rotates around a horizontal axis. The face milling cutter mounted on three or four spindle heads rotate about horizontal axis and remove metal from work pieces supported on the faces of the drum.

c. Tracer controlled milling machine

The tracer controlled milling machine as shown in figure (6) reproduces irregular or complex shapes of dies, moulds.... etc. by synchronized movements of the cutter and tracing element. The feed motion of the machine is controlled automatically by means of a stylus that scans a profiled template or a contoured model which is to be reproduced. The movement of the stylus energizes on oil relay system, which in turn operates the main hydraulic system of a the table. This arrangement is called servomechanism.

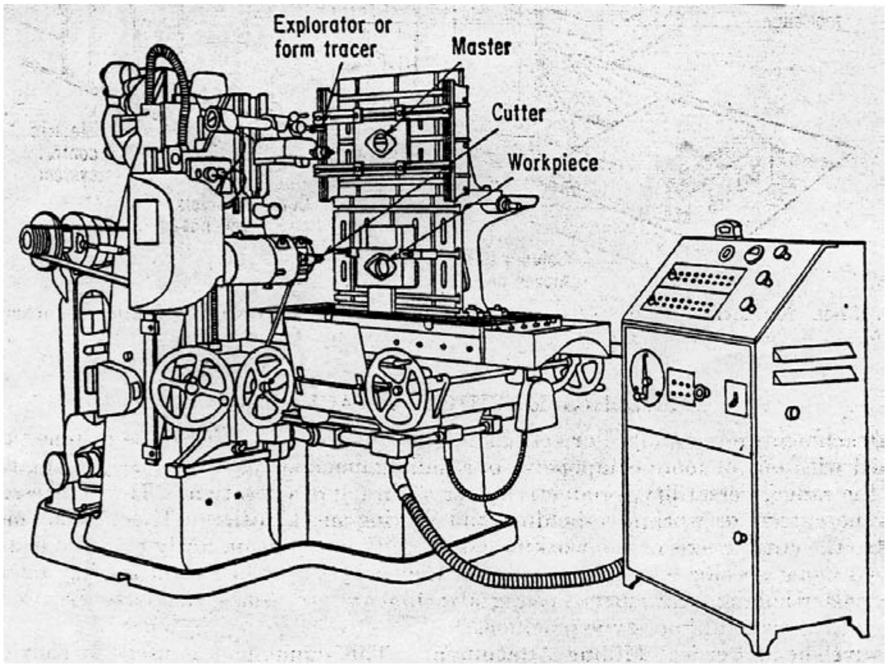
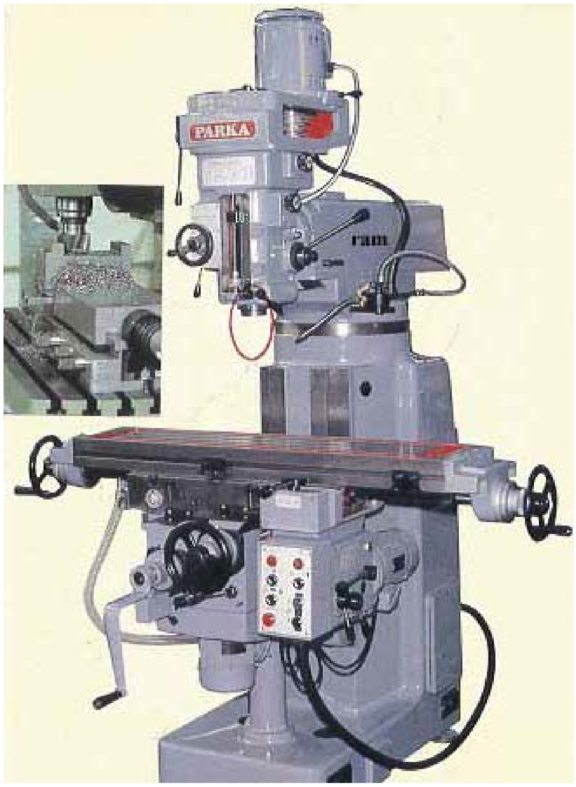


Fig. (6): Tracer-type milling machine

d. Ram-type milling machine

The ram-type milling machine shown in figure (7) is characterized by a spindle mounted to a movable housing on the column to permit positioning the milling cutter forward or backward in a horizontal plane. Two popular ram-type milling machines are available, namely, the universal ram-type milling machine and the swivel head ram-type milling machine. In the case of universal ram-type milling machine, the spindle is mounted on a ram, while keeping all the characteristics of the universal milling machine intact. In the case of swivel head ram-type milling machine, the cutter head containing the milling machine spindle is attached to the ram. The cutter head can be swiveled from a vertical spindle position to a horizontal spindle position or can be fixed at any desired angular position between vertical and horizontal.



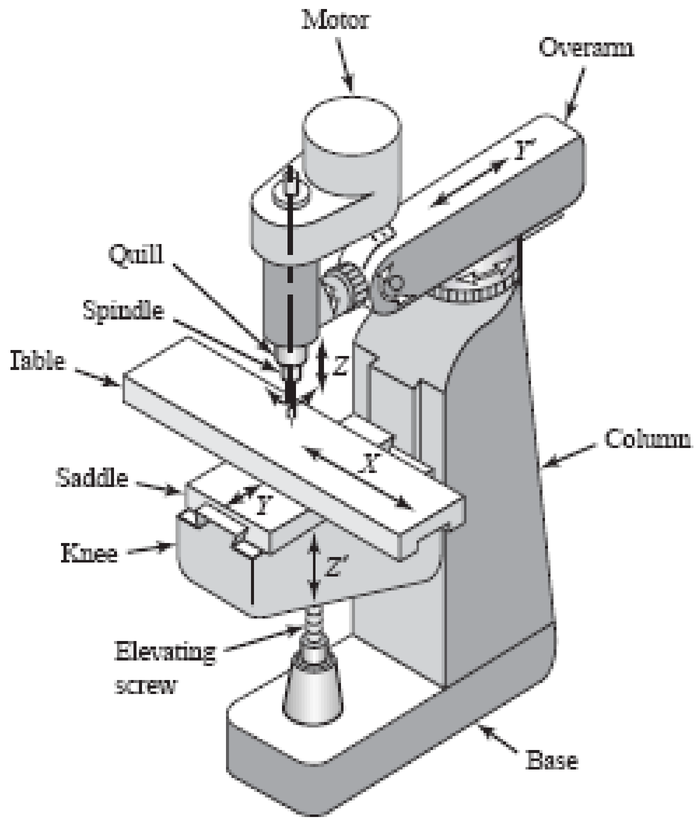


Fig. (7): Ram-type milling machine

Principal parts

The principal parts of a column and knee type milling machine as in figures (8,9) are:

Base: The base of the machine is a grey cast iron casting accurately machined on its top and bottom surfaces and serves as a foundation member for all the other parts which rest upon. It carries the column at its other end. In some machines, the base is hollow and serves as a reservoir for cutting fluid.

Column: The column is the main supporting frame mounted vertically on the base. The column is box shaped, heavily ribbed from inside and houses all the driving mechanisms for the spindle motion & feed motion. The front vertical face of the column is accurately machined and is provided with dovetail guide ways for supporting the knee. The top of the column is finished to hold an over-arm that extends outward at the machine.

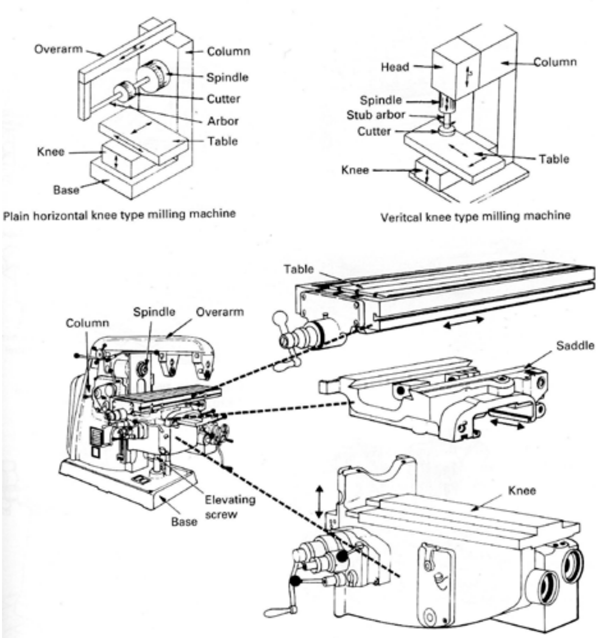
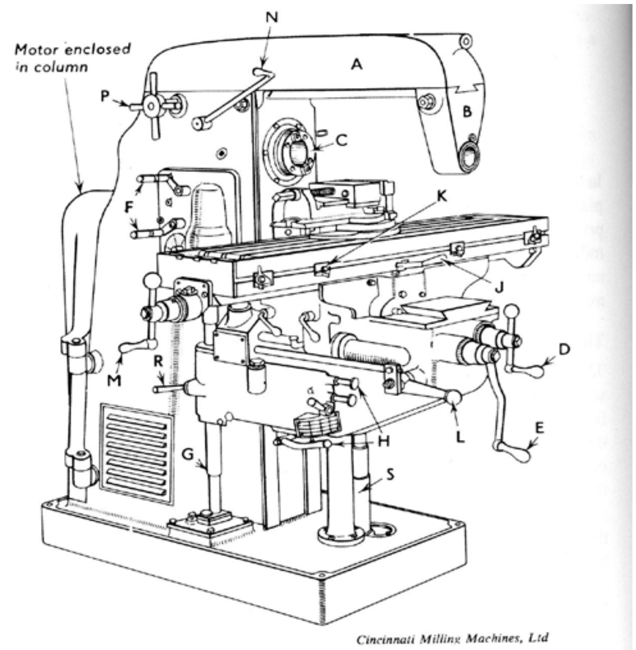


Fig. (8): horizontal milling machine



A, Overarm; *B*, Arbor supporting bracket; *C*, Spindle nose; *D*, Hand cross feed; *E*, Hand vertical feed; *F*, Speed change levers; *G*, Feed driving shaft (enclosed); *H*, Feed change levers; *J*, Table feed actuating lever; *K*, Feed trip; *L*, Rapid power feed control; *M*, Hand table feed; *N*, Starting lever; *P*, Wheel for moving overarm; *R*, Feed reversing lever; *S*, Tube to deliver cutting fluid to reservoir in base.

Fig. (9): parts of horizontal milling machine

Knee: The knee is a rigid grey cast iron casting that slides up and down on the vertical ways of the column face. The adjustment of height is effected by on elevating screw mounted on the base that also supports the knee. The knee houses the feed mechanism of the table, and different controls to operate it.

Saddle: On the top of the knee is placed the saddle, which slides on guide-ways set exactly at 90° to the column face. A cross feed screw near the top of the knee engages a nut on the bottom of the saddle to move it horizontally, by hand or by power, to apply the cross feed. The top of the saddle is accurately machined to provide guide-ways for the table.

Table: The table rests on ways on the saddle and travels longitudinally. The top of the table is accurately finished and T-slots are provided for workplace and other fixtures

clamping. A lead screw under the table engages a nut on the saddle to move the table horizontally by hand or power.

Overhanging arm: The overhanging arm is mounted on the top of the column end extends beyond the column face and serves as a bearing support for the other end of the arbor. The arm is adjustable so that the bearing support may be provided nearest to the cutter. More than one bearing support may be provided for the arbor.

Front brace: The front brace is an extra support that is fitted between the knee and the over-arm to ensure further rigidity to the arbor and the knee when heavy cuts are taken. The front brace is slotted to allow for the adjustment of the height of the knee relative to the over arm.

Spindle: The spindle of the machine is located in the upper part of the column and receives power from the motor through belts, gears and cutters and transmits it to the arbor. The front end of the spindle just projects from the column face and is provided with a tapered hole into which various cutting tools and arbors may be inserted. The accuracy of metal cutting process depends primarily on the accuracy, strength and rigidity of the spindle.

Arbor: An arbor may be considered as an extension of the machine spindle on which milling cutters are securely mounted and rotated. The arbors are made with taper shanks for proper alignment with the machine spindles having taper holes at their noses. The arbor may be supported at the distant end by the over-arm or may be of cantilever type which is called *stub arbor*. The arbor shanks are properly gripped against the spindle taper by a draw-bolt, which extends throughout the length of the hollow spindle. The threaded end of the draw-bolt is fastened to the tapped hole of the arbor shank and then the locknut is tightened against the spindle. This causes the arbor shank to be pulled inside, gripping it firmly against the taper hole of the spindle; the spindle has also two keys for imparting positive drive to the arbor in addition to the friction developed in the taper surfaces. The ejection of the arbor is effected by unscrewing the locknut and then tapping the draw-bolt lightly. The cutter is set at the required position of the arbor by

spacing collars or spacers of various lengths but of equal diameter. The entire assembly of the milling cutter and the spacers are fastened to the arbor by a long key. The end spacer on the arbor is slightly larger in diameter and acts as a bearing bush for bearing support which extends from then over-arm. The whole set up is locked from the end by the arbor nut. Figure (10) illustrates an arbor assembly and the draw-bolt arrangement for locking the arbor with the spindle. A shell-end-mill arbor is shown in figure (11). Such arbor is used for mounting cutters and shell-end-mills on plain, universal, and vertical milling machines. Such arbors are inserted with their taper shank in the taper hole of the spindle and are clamped by a draw-in bolt passing through the hollow milling machine spindle. The cutters or end mills are retained from rotation by a key and are clamped by screw.

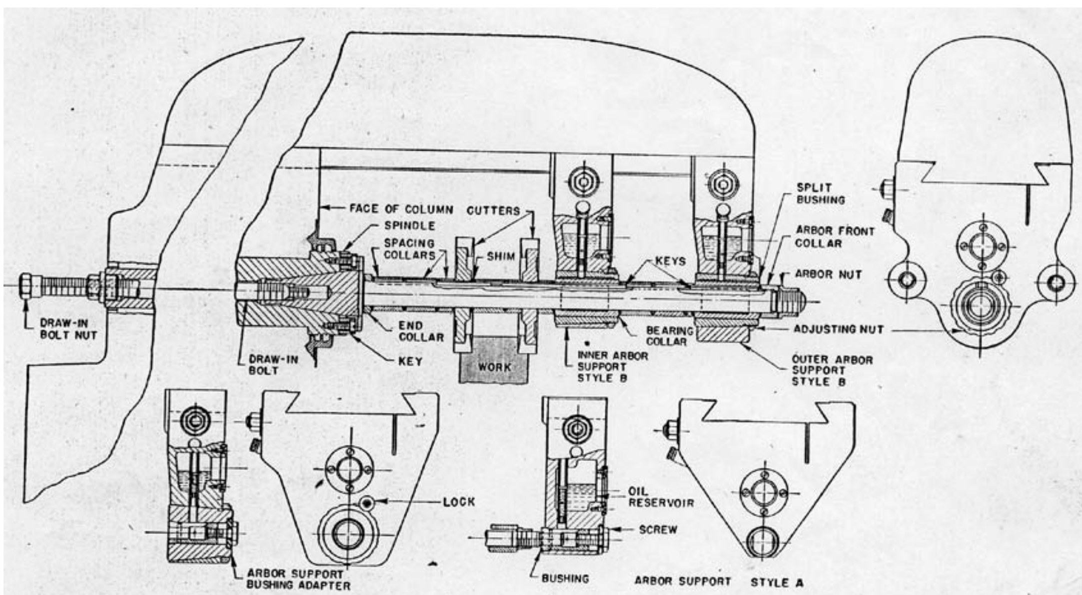


Fig. (10): Section through an arbor

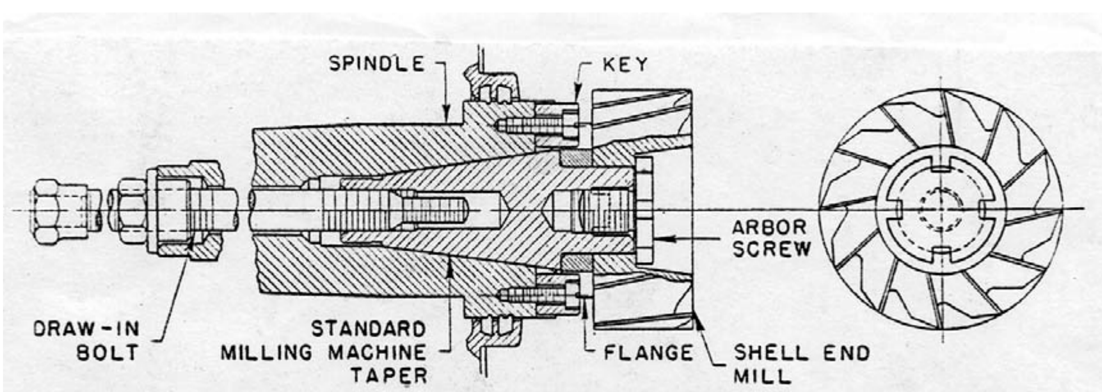


Fig. (11): Mounting of shell-end-mill

Specification of milling machine

The milling machine of the knee and column type, for example, is characterized by the dimensions of the working surface of the table and its maximum length of longitudinal, cross and vertical travel of the table. In addition to the above dimensions, number of spindle speeds, number of feeds, spindle nose taper, power available, net wt. and the floor space required, …etc. should also be stated in order to fully specify the machine.

Cutters, holding devices

There are several methods of supporting and rotating milling cutters with the machine spindle depending on the different designs of the cutter. The following are the different devices for holding rotating cutters.

Arbors: The cutters having a bore at the centre are mounted and keyed on a short shaft called arbor which is connected with the milling machine spindle by a draw bolt end driving keys. The complete assembly of an arbor with the holding and rotating arrangement has been shown in figure (10).

Collets: A milling machine collet (figure 12) is a form of sleeve bushing for reducing the size of the taper hole at the nose of the milling machine spindle so that an arbor or a milling cutter having a smaller shank than the spindle taper can be fitted in.

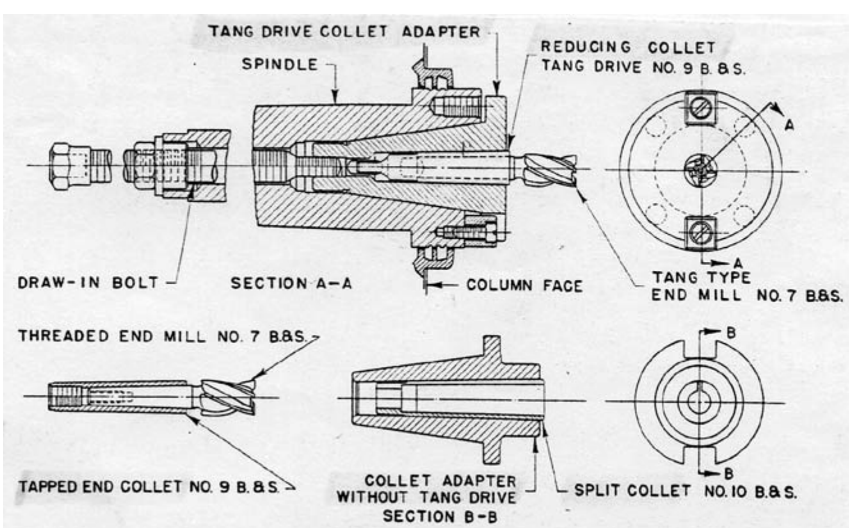


Fig. (12): Adapters and collets for self-releasing and self-holding collets

Spring collets: Straight shank cutters are usually held in a special adapter called "spring collet" or spring chuck. The nose end of the collet is tapered from inside and threaded for a small distance from outside. An adapter, split from its front end by 3 equally spaced slots, is fitted into the tapered nose of the collet. The cutter shank is introduced in the cylindrical hole provided at the end of the adapter and then the nut is tightened. This causes the split jaws of the adapter to spring in side and grip the shank firmly as shown in figure (13).

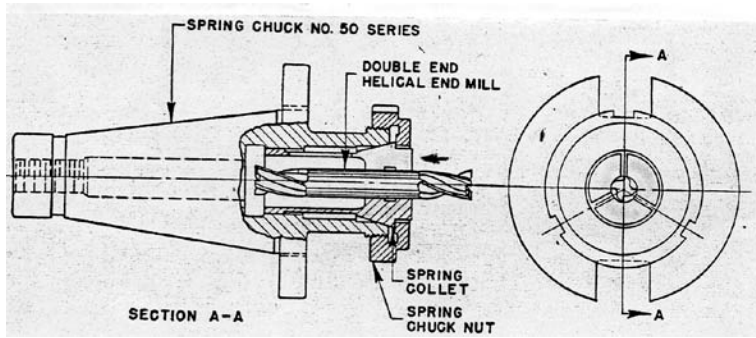


Fig. (13): Spring-chuck collet

Bolted cutters: The face milling cutters of large diameter having no shank are bolted directly on the nose of the spindle as shown in figure (14).

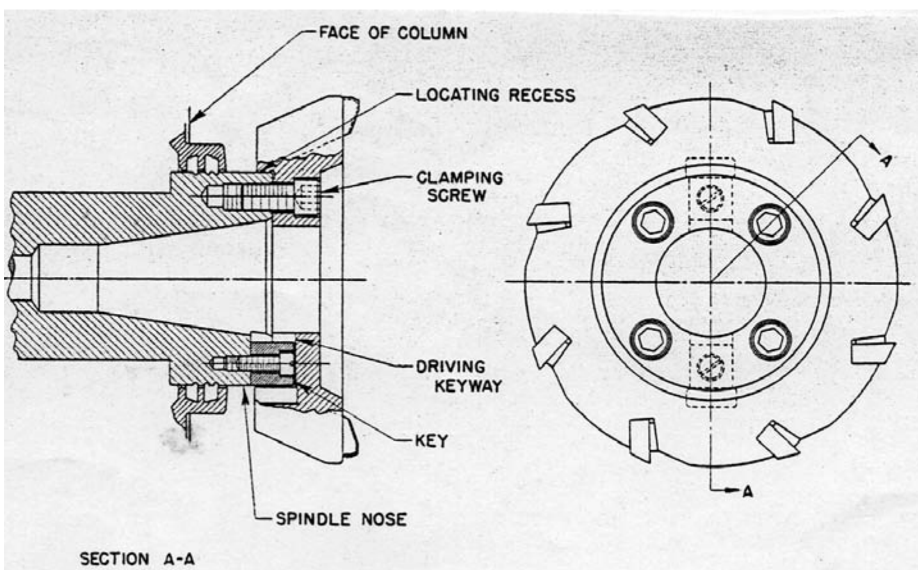


Fig. (14): Mounting a face mill on the spindle nose of a milling machine

Screwed on cutters: The small cutters having threaded holes at the centre are screwed on the threaded nose of an arbor which is mounted on the spindle in the usual manner.

Milling cutters

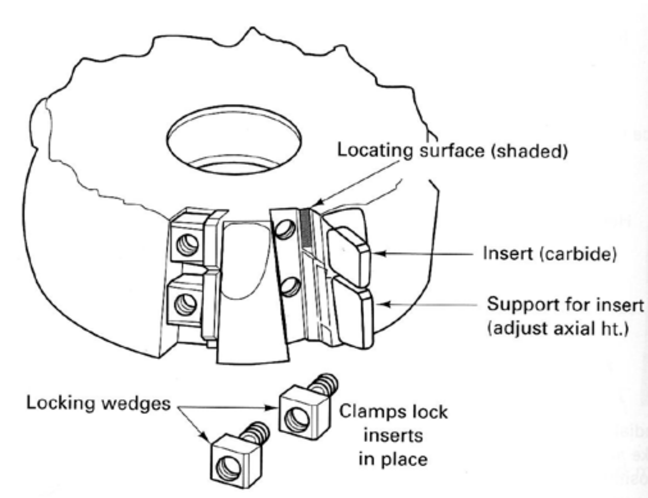
The milling cutters are revolving tools having one or several cutting edges of identical form equally spaced on the circumference of the cutter. The cutting elements are called teeth which intermittently engage the workpiece and remove material by relative movement of the workpiece and cutter. Milling cutters may be classified according to:

1. **The constructional feature of the cutter:**
    a. Solid cutter.
    b. Tipped solid cutter.
    c. Inserted teeth cutter.
2. **The methods of mounting the cutter:**
    a. Arbor type cutter.
    b. Shank type cutter.
    c. Facing type cutter.
3. **The direction of rotation of the cutter:**
    a. Right hand rotational cutter.
    b. Left hand rotational cutter.
4. **The direction of helix of the cutter teeth:**
    a. Parallel or straight teeth cutter.
    b. Right hand helical cutter.
    c. Left hand helical cutter.
    d. Alternate helical teeth cutter.
5. **The purpose of use of the cutter:**
    a. Standard milling cutter.
    b. Special milling cutter.

Solid cutter: A solid cutter has teeth integral with the cutter body. The cutters are of smaller diameter and width and made of one piece material usually of high speed steel.

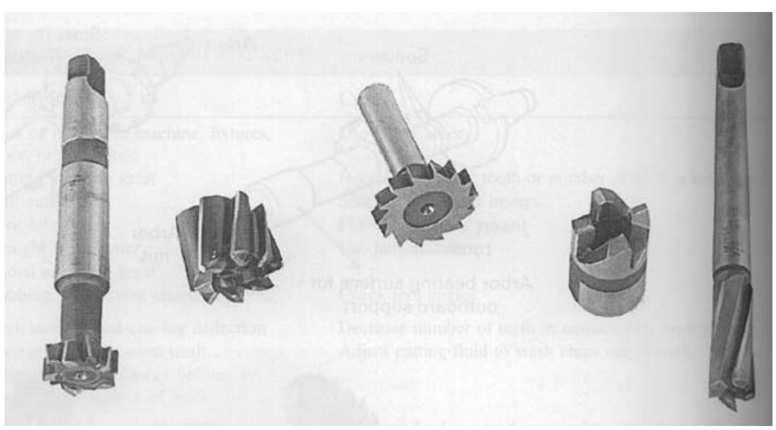
Tipped solid cutter: A tipped solid cutter is similar to a solid cutter, except that the cutter teeth are made of cemented carbide which are brazed on the tool shanks of an ordinary tool steel cutter body to reduce the cost of the cutter.

Inserted teeth cutters: In large milling cutters, the teeth or blades are inserted or secured in a body of less expensive materials. The blades are usually held in the cutter body by mechanical means.



Arbor type cutter: The arbor type cutters are provided with a central hole having a keyway for mounting them directly on the milling machine arbor. Milling cutters having tapered or threaded holes are also available. They are mounted on arbors of different designs.

Shank type cutter: The shank type cutters are provided with straight or tapered shank integral with the cutter body. The straight or tapered shanks are inserted into the spindle nose and are clamped to it either by friction or by a draw bolt.



Facing type cuter: The facing type cutters are either bolted or attached directly to the spindle nose, or secured on the face of a short arbor called *stub arbor*. The facing type cutters are mainly used to produce flat surfaces.

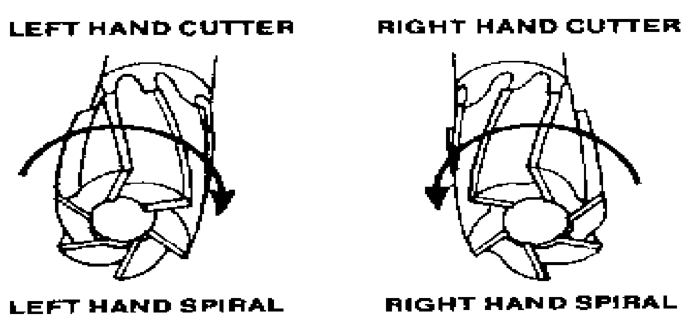
Right hand cutter: A milling cutter is considered to be a right hand cutter when it rotates in an anticlockwise direction when viewed from the end of the spindle.

Left hand cutter: A milling cutter is considered to be a left hand cuter if it rotates in a clockwise direction when viewed from the end of the spindle.

Parallel or straight teeth Cutter: The parallel or straight teeth cutters have their teeth straight or parallel to the axis of rotation of the cutter. The helix angle of parallel teeth cutters is equal to zero.

Right hand helical teeth cutter: These cutters have their teeth cut at an angle to the axis of rotation of the cutter. The cutter may be distinguished viewing it from one of its end faces, when the helical groove or flute will be found to lead from left to right hand direction of the cutter body.

Left hard helical teeth cutter: These cutters have their teeth cut at an angle to the axis of rotation of the cutter. The cutter may be distinguished by viewing it from one of its end faces when the helical groove or flute will be found to lead from right to left hand direction of the cutter body.



Alternate helical teeth cutter: In some cutters the alternate teeth are provided with right and left hand helical angles.

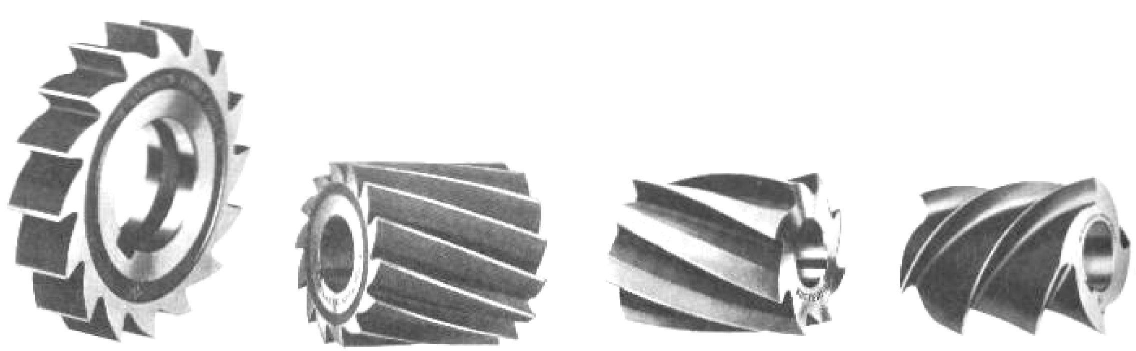
Standard milling cutter: These cutters are conventional type of milling cutters whose dimensions (such as cutter diameter and width, diameter of centre hole, width and depth of keyways, ... etc.) are standardized.

Special milling cutters: Special milling cutters are designed to perform special operations.

Standard milling cutters:

There are many different types of standard milling cutters. They are classified into:

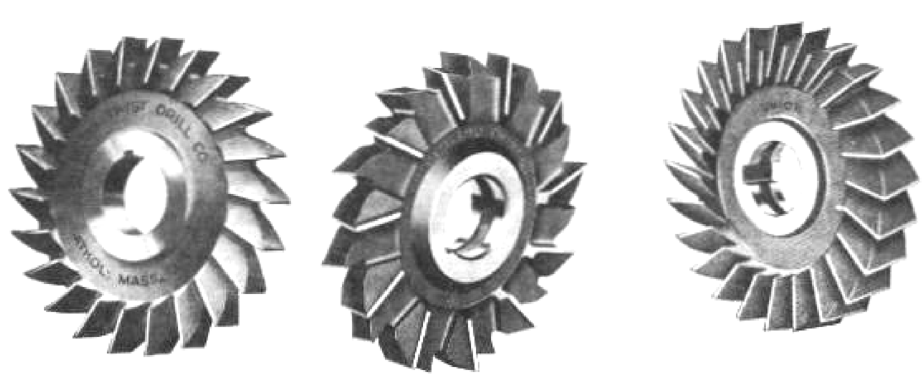
1. **Plain milling cutters:**
    a. Light duty plain milling cutter.
    b. Heavy duty plain milling cutter.



a b c d

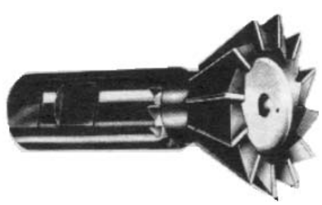
Plain milling cutters (a) light duty, (b) light duty helical, (c) heavy duty, (d) high helix.

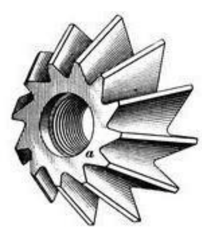
2. **Side milling cutters**

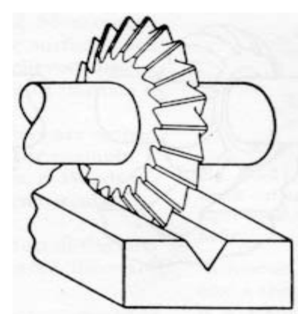


3. **Face milling cutters**

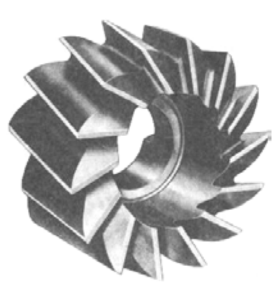
4. **Angle milling cutters.**
    a. Single angle milling cutter.
    b. Double angle milling cutter,

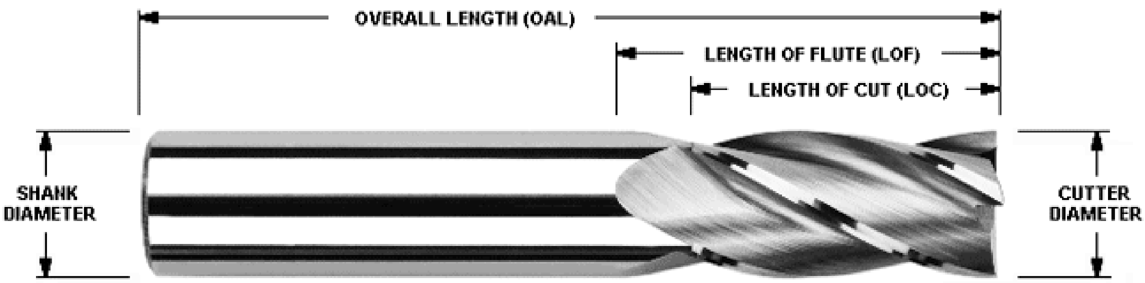


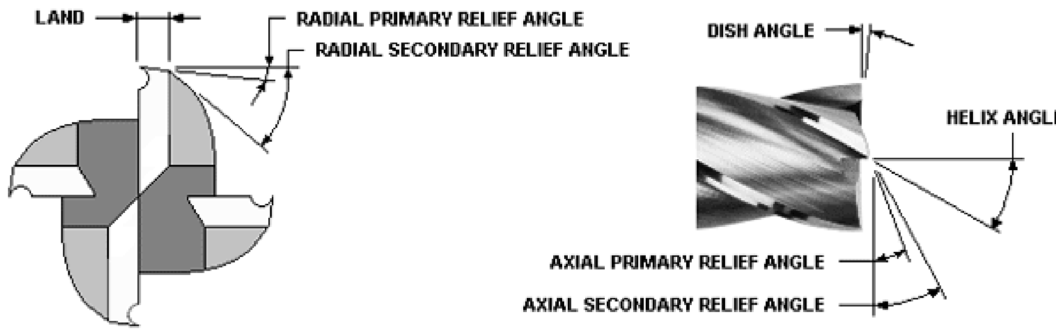


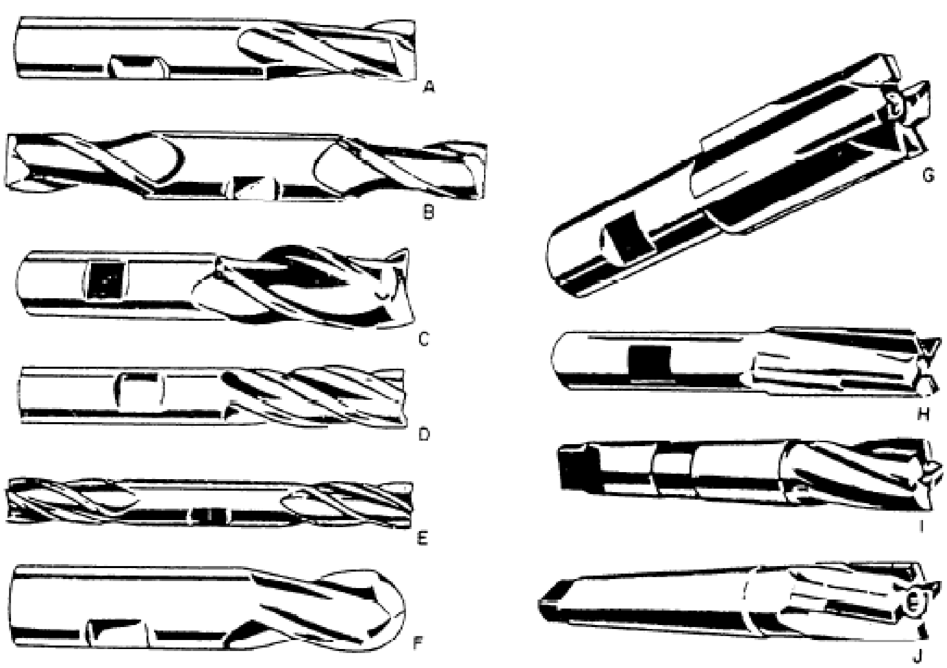


5. **End mills**
    a. Taper shank end mill.
    b. Straight shank end mill
    c. Shell end mill





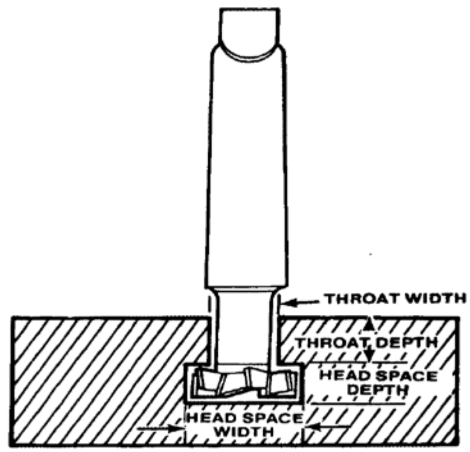




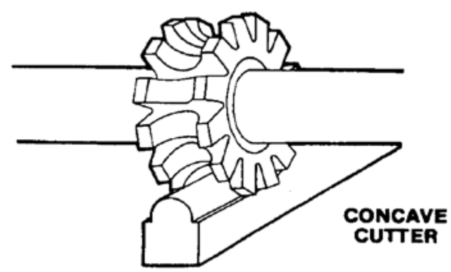
A. Two-flute single-end
B. Two-flute double-end
C. Three-flute single-end
D. Multiple-flute singleend
E. Four-flute double-end

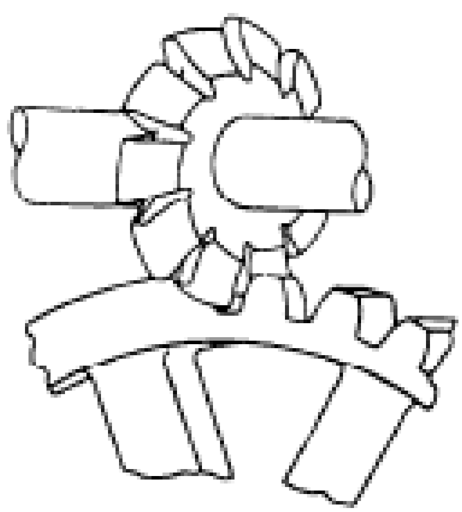
F. Two-flute ball-end
G. Carbide-tipped, straight flutes
H. Carbide-tipped, right-hand helical flutes
I. Multiple-flute with taper shank
J. Carbide-tipped with taper shank and helical flutes

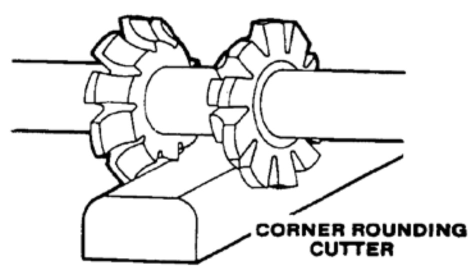
6. **T-slot cutters**

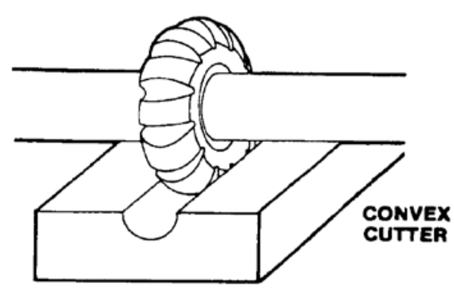


7. **Form cutters**
   a. Convex milling cutter.
   b. Concave milling cutter.
   c. Corner rounding milling cutter.
   d. Gear cutter



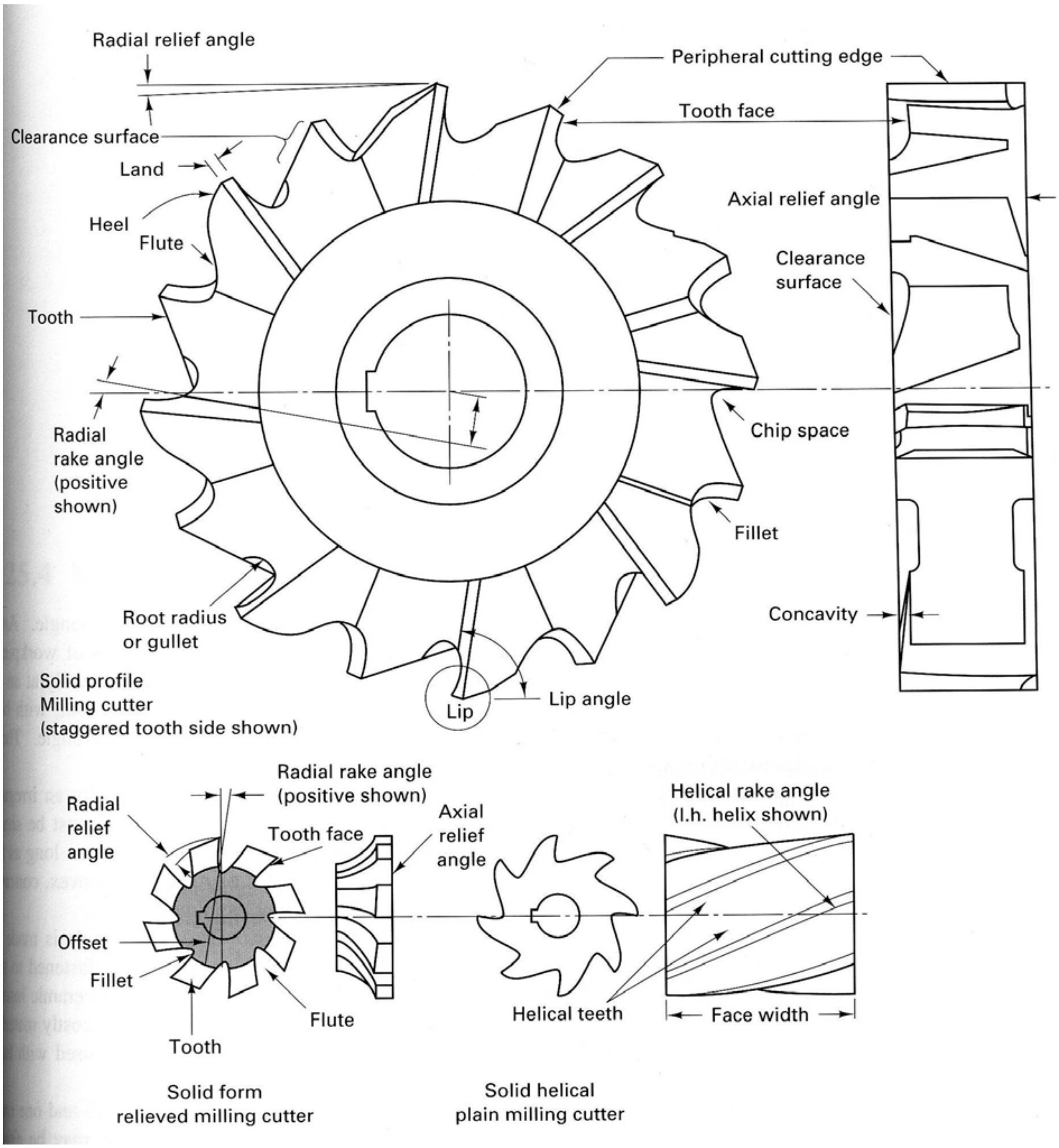






Elements of a plain milling cutter:

The principal parts and angles of a plain milling cutters as illustrated in the following figure are:



Body o cutter: The part of the cutter left after exclusion of the teeth and the portion to which the teeth are attached.

Cutting edge: The edge formed by the intersection of the face and the circular land or the surface left by the provision of primary clearance.

Face: The portion of the gash adjacent to the cutting edge on which the chip impinges as it is cut from the work.

Fillet: The curved surface at the bottom of gash which joins the face of one tooth to the back of the tooth immediately ahead.

Gash: The chip space between the back of one tooth and the face of the next tooth.

Land: The part of the back of the tooth adjacent to the cutting edge which is relieved to avoid interference between the surface being machined and the cutter.

Lead: The axial advance of the helix of the cutting edge in one complete revolution of the cutter.

Outside diameter: The diameter of he circle passing through the peripheral cutting edge.

Root diameter: The diameter of the circle passing the rough the bottom of the fillet.

Cutter angles: The milling cutter teeth are provided with rake, clearance and other cutting angles in order to remove metal efficiently.

Relief angle: The angle between the land of a tooth and the tangent to the outside diameter of cutter at the cutting edge of that tooth.

Primary clearance angle: The angle formed by the back of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Secondary clearance angle: The angle formed by the secondary clearance surface of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.

Radial rake angle: The angle measured in the diametral plane between the face of the tooth and a radial line passing through the tooth cutting edge. The rake angles may be positive negative or zero.

Lip angle: The included angle between the land and the face of the tooth, or alternatively the angle between the tangent to the back at the cutting edge and the face of the tooth.

Helix angle: It is the angle included between a tangent to the cutting edge and a line drawn parallel to the cutter axis measured in a tangential plane to the cutter periphery.

Influence of tooth angles on cutter performance

Helix angles:

The cutters with helix angles have the following advantages:

1. The helical cutters are smoother than straight ones. This is due to the fact that their teeth cut in the workpiece gradually without causing any hammer action or sudden load as is the case with straight teeth. As a result the chattering effect is eliminated and the surface finish is better.
2. The power consumption is reduced when using helical cutters due to the reduction of chatter which causes fluctuation and increase in power input.

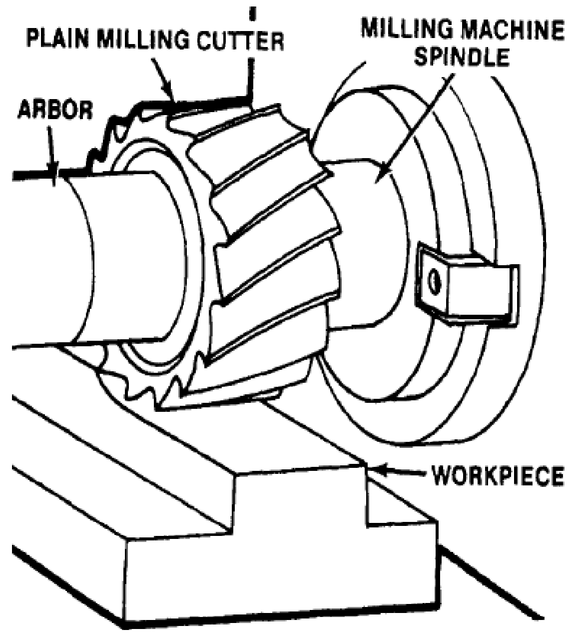
The cutter helix angle should range between 25 and 45°. Excessive amount of helix angles increases thrust on the spindle bearings and thus causes big deflections of machine tool parts and produces a poor surface finish and low accuracy.

Fundamentals of the milling process:

The various processes performed by different milling cutters may be grouped under two separate headings; **Peripheral milling and face milling**:

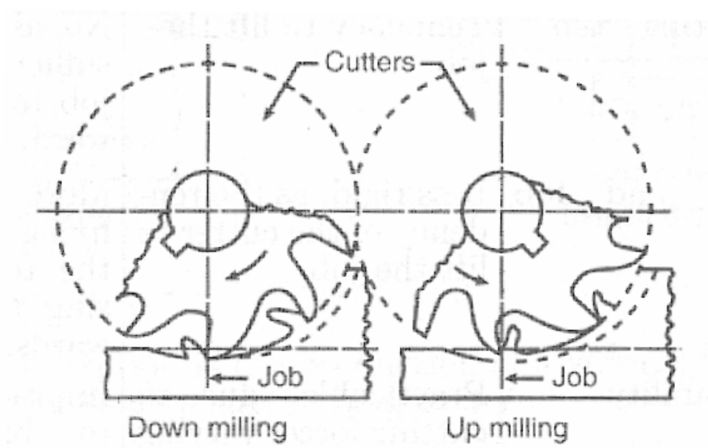
Peripheral milling:

The peripheral milling is the operation performed by a milling cutter to produce a machined surface parallel to the axis of rotation of the cutter. In peripheral milling the cutting force is not uniform throughout the length of the cut by each tooth. Due to that a shock is developed in the driving mechanism of the machine that leads to vibration. The quality of surface generated and the shape of the chip formed are dependent upon the rotation of the cutter relative to the direction of feed movement of the work. According to the relative movement between the tool and the work, the peripheral milling is classified under two headings; **up-milling and down-milling**.



Up-milling: The up-milling or conventional milling is the process of removing metal by a cutter which is rotated, against the direction of travel of the workpiece. The thickness of the ship in up-milling is minimum at the beginning of the cut and it reaches a maximum when the cut terminates, consequently the cutting force increases from zero to a maximum. The cutting force is directed upwards and tends to lift the workpiece from its fixture. In up-milling there is difficult access of coolant to the cutting edge as it begins cut. As the cutter progresses, the chips accumulate at the cutting zone, and may be carried over with the cutter spoiling the work surface. The surface milled by up-milling appears to be slightly wavy as the cutter teeth do not begin their cut as soon as they touch the work surface. The up-milling process, being safer is still commonly used in spite of its disadvantages.

Down-milling: The down-milling or climb milling is the process of metal removal by a cutter which is rotated in the same direction of travel of the workpiece. The thickness of the chip is maximum then the cut begins. The cutter tooth starts removing metal immediately on the reaching the workpiece surface without sliding, as it can apply a sufficient bite on the work (it slides in case of up-milling). The cutting forces in down-milling are also variable throughout the cut from a maximum when the tooth begins its cut to a minimum when the tooth leaves the work. In down-milling, the fixture design becomes easier as the direction of the cutting force ends to seat the work firmly in the work holding devices. The chips are also disposed off easily without interference with the cutter. The coolant can be poured directly at the cutting zone where the cutting force is maximum. This result in improved surface finishes and diminishes the heat generated. The down-milling operation having so many advantages connot be used on old machines due to the backlash error that may be present between the feed screw of the table and the nut. The backlash error causes the work to be pulled below the butter when the cut begins and leaves the work free when the cut is terminated. The same action is repeated as soon as the next tooth engages the work. This results in vibration to be set upon the workpiece and damages the work surface considerably. The down-milling should be only be performed on rigid machines provided with backlash eliminator.



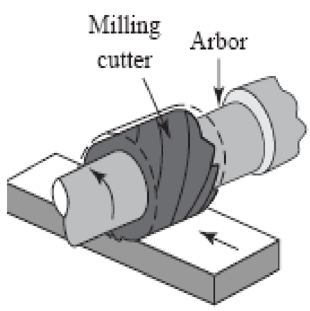
Face milling

The face milling is the operation performed by a milling cutter to produce a flat machined surface perpendicular to the axis of rotation of the cutter. The peripheral cutting edges of the cuter do the actual cutting, whereas the face cutting edges finish up

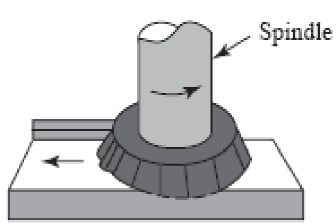
the work surface by removing a very small amount of material. In face milling operation both the up and down milling are performed simultaneously on the work surface. When the cuter rotates through half of the revolution, the direction of movement of the cutter tooth is opposite to the direction of feed and the condition reverses when the cutter rotates through other half of the revolution. The thickness of the chip is minimum at the beginning and at the end of the cut; and it is maximum when the work passes through the centre line of the cutter. The surface generated in face milling is characterized by the tooth circular marks of the cutter. The length of the face cutting edges should be greeter than the amount of feed as the function of these cutting edges is to smoothen the circular works left by peripheral cutting edges.

End milling:

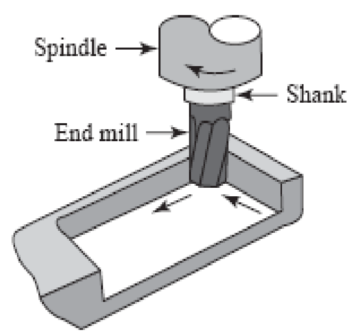
The end milling may be considered as the combination of peripheral and face milling operations. The cutter has teeth both on the end face and on the periphery. The cutting characteristics may be of peripheral or face milling type depending on the particular cutter used. When the end cutting edges are only used to remove metal, the direction of rotation and the direction of helix of the cutter should be the same. When the peripheral cutting edges are used to remove metal the direction of rotation and the direction of helix should be opposite to each other.



Peripheral milling



Face milling



End milling